CONF-840945--11

LA-UR--84-3506

DE85 002713

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TITLE: NUCLEAR PHYSICS IN THE 10-300 MeV ENERGY RANGE USING A PULSED WHITE NEUTRON SOURCE

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SUBMITTED TO: Neutron Nucleus Collisions - A Probe of Nuclear Structure, Glouster, OH, September 5-8, 1984.

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NUCLEAR PHYSICS IN THE 10-300 MeV ENERGY RANGE USING A PULSED WHITE NEUTRON SOURCE

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ABSTRACT

A new pulsed white neutron source is under construction at the Los Alamos WNR facility. The neutrons are produced by LAMPF proton micropulses striking thick targets of various materials. Beam parameters include energy of 800 MeV, pulse rate of approximately 50,000 Hz, 0.4 nsec pulse width, average current as high as 6μa, and a useful neutron energy range from 3 to 300 MeV. The facility will receive beam approximately 80% of the time LAMPF is operational; it increases by a factor of 1000 the experimental capability over the present system at the WNR when beam intensity, angular distribution, and availability are taken into account. In addition to established white source techniques, the facility is also highly competitive with monoenergetic sources for a wide class of experiments such as neutron capture γ ray spectroscopy and neutron-induced charged particle reactions. The facility should be operational in about nine months. Arrangements are underway to make the facility readily accessible to visiting experimenters.

INTRODUCTION

A new pulsed white neutron source is presently under development as part of the Low Alamos Weapons Neutron Research (WNR) facility. The WNR facility, which is located to the south of the primary Los Alamos Meson Physics Facility (LAMPF) experimental area, receives LAMPF beam for production of neutrons or neutrinos at three target areas. Presently nuclear physics in the 3-300 MeV range is conducted using a white source at WNR Target Area 1. However this part of the facility is being modified for use as an epithermal pulsed neutron source for condensed matter physics studies using neutron scattering techniques. The MeV neutron physics capabilities are therefore being reestablished at Target Area 2 (the Blue Room). Greatly improved running conditions will be possible as a result of greater average beam current, higher repetition rate, neutron emission at forward angles, and a larger fraction of total LAMPF operating hours.

This paper describes the capabilities and operating characteristics of the new white source with particular attention to the high neutron intensity possible. The experimental program presently planned for the facility is described along with a summary of other possible research opportunities including some which are not traditionally pursued using white source methods. It will be shown that this intense white source is competitive for many experiments ordinarily pursued with monoenergetic sources. As an example the performance of a possible facility at the WNR/PSR for (n,p) studies in the 10-300 MeV neutron energy range is compared with the traditional monoenergetic source approach. These white source facilities will be available to visitors for collaborative research during most of LAMPF's operation. It might be possible to provide neutron beams for spectrometer construction and research led by outside teams of scientists. The new facility is expected to begin operation with a limited array of experimental capabilities in mid-1985. Further improvements to the facility will be made during LAMPF down periods over the next two years in accordance with basic and applied research needs and available funding.

II FACILITY DESCRIPTION

Fig. 1 shows the WNR/PSR facility. The Proton Storage Ring (PSR) shown in the upper right hand corner of the figure will become operational in the summer of 1985. A new neutrino facility, Target Area 3, located off the left hand side of the figure and was completed in 1984. This facility will become operational in 1985. The rectangular building in the center is the location of the Target Area 1 which is devoted primarily to neutron production for materials science studies. The dome shaped structure is Target Area 2 which is being prepared as an intense white source of MeV neutrons.

Each of the three target areas requires different beam conditions in terms of pulse rate and pulse width; however all use the same beam energy of 800 MeV for their primary programs, and this makes a fully multiplexed operation possible. Target area 1 accepts the PSR output of 270 nsec wide pulses with a 12-Hz rate and with an average current of 100 μa. Target Area 3 (neutrinos) now is able to accept approximately 20 μa of LAMPF beam supplied as 850-μsec long pulses at the rate of about 2 Hz; this current might grow significantly in the future. Target Area 2 of primary interest here is being prepared to accept up to 6 μa of beam at a rate of 50,000 Hz and a width of 0.4 nsec.

The means of beam delivery to Target Area 2 is somewhat complex. The H^- beam for this mode is accelerated

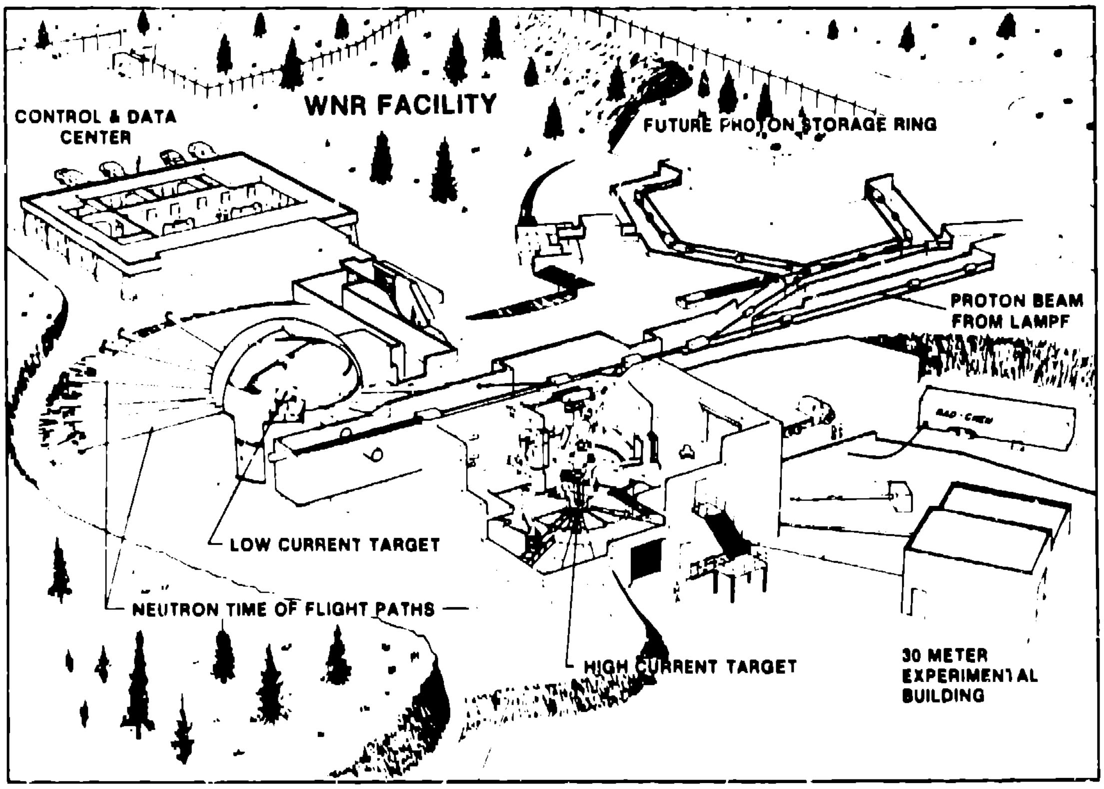

Fig. 1 - The storage ring in the upper right hand corner feeds the high current target area in the center where condensed matter physics and low energy neutron nuclear physics is conducted. The dome structure is the site of the white source discussed here.

simultaneously with the high current H^+ beam to LAMPF Target Area A. That is, two injectors operate during the same LAMPF macropulse, one producing H^- and the other H^+ beam. The H^+ beam consists of the normal LAMPF microstructure with the 5 nsec spacing between microbursts associated with the 200 MHz LAMPF frequency. The H^- beam is chopped so as to increase the spacing between pulses from the natural 5 nsec to 1 μsec. In the process a buncher in the H^- injector approximately doubles the number of H^- ions per burst. The average H^- current is therefore 1% of the H^+ beam; the H^- bursts are accelerated 180° out of phase with the H^+ beam. The two beams are magnetically separated in the LAMPF switchyard after acceleration and the ^-H beam bent 90° toward the WNR/PSR complex.

Table I shows the present plan for LAMPF beam distribution for the immediate future. Note that Line X receives polarized H^- beam with variable energy at a rate of 40 Hz. Since the new H^- injector contructed as part of the PSR project can inject the same high current beam as the H^+ injector, the LAMPF accelerator can be fully loaded with H^- beam. This H^-beam is directed to the PSR (and then to Target Area 1) and to Target Area 3 at the approximate rate of 12 and 2.5 Hz respectively. The remainder (65.5 Hz) of the time the LAMPF accelerator is in the dual H^+ - H^- mode and supplies beam simultaneously to Area A and to Target Area 2. The average beam current in Target Area 2 when LAMPF is operating at full capacity is therefore:

$$1.3 \times 10^3\ \mu a \times (65.5/120) \times 0.01 = 7\ \mu a.$$

Table I - LAMPF Beam Distribution

Experimental Area	Macropulse Rep. Rate Hz	Beam* Type	Energy (MeV)
Line X	40	P^-	Variable
Area A	65.5^+	H^+	800
Target Area 2 MeV Neutron Nuclear Science	65.5	H^-	800
Target Area 1 PSR-Neutron Scattering	12	H^-	800
Target Area 3 Neutrino Research	2.5	H^-	800
	120.		

* H^+ - protons, H^- - negative hydrogen ions, p^- - polarized negative hydrogen ions.

$^+$ These two modes run simultaneously. The frequency actually will be somewhat different since LAMPF cannot run at half-integer rates.

A typical current of 6 μa is assumed for nominal operation here. The repetition rate is about 50,000 Hz.

Part of the development of the facility is a beam transport system which allows full multiplexing of the beam so that all these facilities can be operated simultaneously. This is shown in Fig. 2, which is not drawn to scale. Not shown at the top of the figure is a 120 Hz switching magnet in the LAMPF switchyard which will be required to allow beam

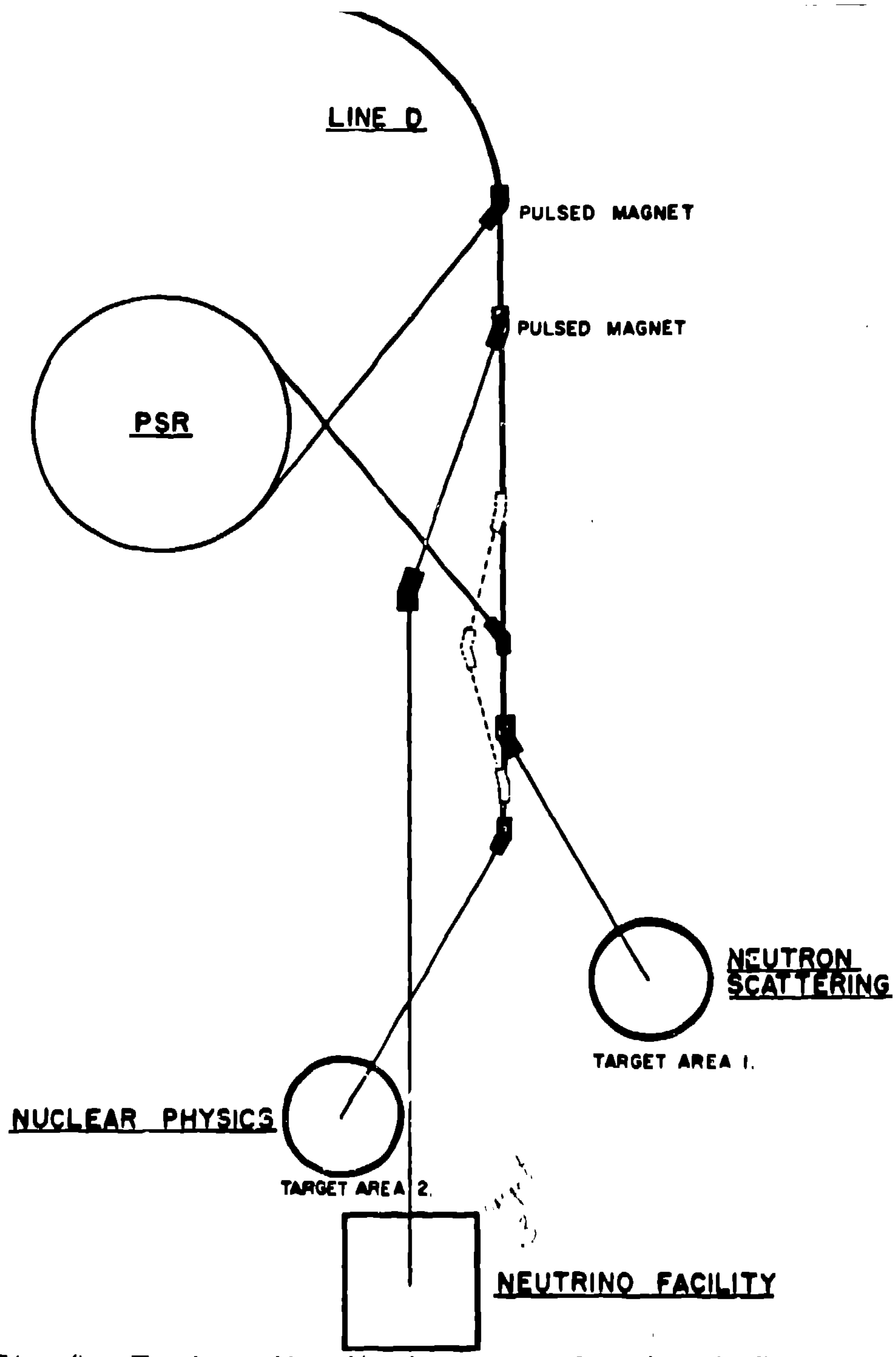

Fig. 2 - The beam distribution system for the WNR/PSR. The first pulsed magnet at the top of the page directs beam into the PSR and from there to Target Area 1. The second pulsed magnet directs some of the remaining beam to the neutrino facility. The remaining beam is directed by the by-pass line (components indicated by dashed lines) to Target Area 2 for MeV neutron nuclear physics.

from any LAMPF macropulse to be directed into the WNR/PSR complex. This magnet will replace a 24-Hz magnet presently in the same position. The line drawings show three routes for beam in the complex. All beam paths shown in solid lines are now or will be in place by spring of 1985.

1) Using the first pulsed magnet in the line at the top of the figure beam can be directed into the PSR, bunched, and then directed to Target Area 1 as shown.

2) Some of the beam, which was not removed by the first pulsed magnet, may be removed by the second pulsed magnet for direction to the neutrino facility. This line is now in place and operational at 20 μa.

3) Beam not removed by either of the two pulsed magnets can be diverted by a system of d.c. magnets into Target Area 2 for MeV neutron nuclear physics studies. The bypass line shown as dashed lines in the drawing is not in place, but installation is planned for 1985. Beam is presently transported on an exclusive use basis as indicated in Fig. 2 into Target Area 2. Note that it will be possible on occasion to transport small amounts of PSR beam ($\sim 10^{15}$ neutrons per 270 nsec burst) into Target Area 2 using the route shown by the solid line, although this mode is expected to be used only on rare occasions.

A comparison of the new capability under construction at Target Area 2 with the present capability at Target Area 1 and with a proposed short burst (1 nsec) mode of the PSR is given in Table II. The latter capability is optimized for the 0.1-3 MeV range, but there are presently no firm plans for implementing it. Note that the advantages of the new arrangement in Target Area 2 over that in Target Area 1 are:

TABLE II

WNR/PSR White Source Comparison

	Target Area 1	Target Area 2	Proposed
H^- beam energy (MeV)	800	800	800
H^- pulse spacing (μsec)	1	1	1380
H^- pulse rate (Hz)	8000	50,000	720
H^- pulse width (nsec)	0.4	0.4	1.0
H^- average current (μamps)	0.07	6	12
Target	W		
Angle of Neutron Emission (Degrees)	90°		

- approximately 100 times the average current
- enhanced intensity of higher energy neutrons using the forward angle
- approximately six times the repetition rate
- much greater facility availabiltiy

These factors combined together represent an extraordinary step beyond the capability of Target Area 1 for MeV neutron nuclear physics studies. The new source strength at Target Area 2 integrated over all angles using a ^{238}U target is 10^{15} n/s with a substantial enhancement of the intensity for neutrons above 10 MeV in the forward direction. The neutron spectrum(1) as a function of energy at 90° is given in Fig. 3. The intensity is given per unit lethargy ($U \equiv \ln E_o/E$). It is easily shown that

$$N(E) = N(U)\ (1/E).$$

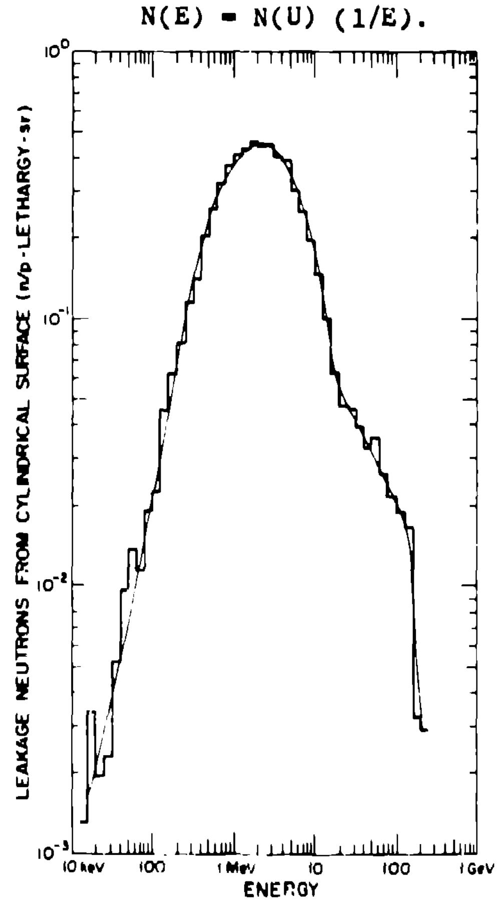

Fig. 3 - The neutron spectrum observed at 90° to the proton beam produced by protons striking a thick ^{238}U target. The definition of lethargy is given in the text.

The neutron intensity at 100 MeV in a 1-MeV wide band is found to be (3.6×10^{13} p/sec) X (0.02 n/p-sr-lethargy) X (1/100 MeV) X (1MeV) X (2.5 (forward angle enhancement factor)) = 1.8×10^{10} n/sec-sr-MeV.

A vertical section through the Target Area 2 is shown in Fig. 4. A 4-ft. thick steel- concrete enclosure around the white source is planed as shown to enclose the white source which is located at the center of the 40 ft. diameter dome shaped cell. Limited working space in a relatively high background area outside of the 4-ft. thick shield will be available with a typical path length of 5 meters. As shown in Fig. 1 several neutron drift tubes penetrate the shielding to the outside of the dome where experiments can be established at a flight path of about 22 meters or beyond. Space is available at 0° to the proton beam direction for a drift tube extending to 250 Meters. Experience with 0° (p,n) measurements in the 500-800 MeV range demonstrate[2] that the effects of air scattering on the neutron spectrum is unimportant for drift paths of that length and for neutrons in that energy range.

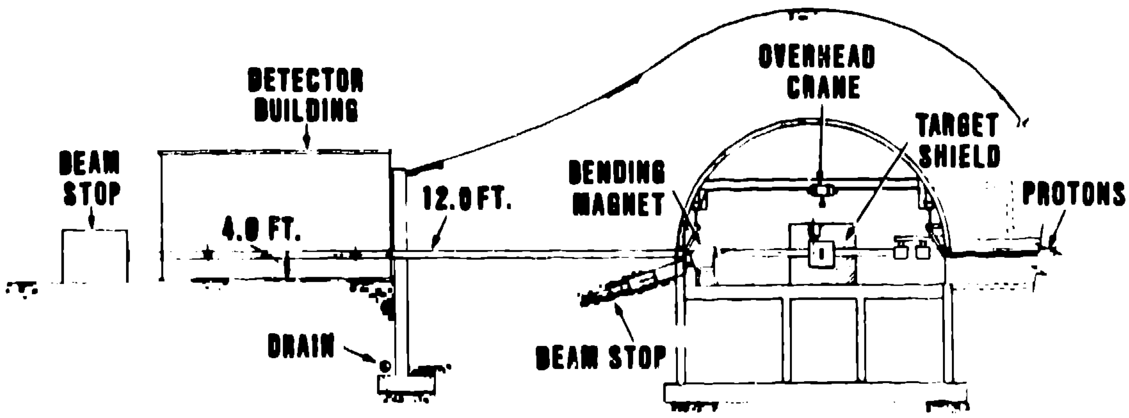

Fig. 4 - A cross sectional view of one of the neutron drift tubes associated with the MeV white source under construction.

III EXPERIMENTAL RESEARCH PROGRAM

An exploratory research program has been carried out in Target Area 1 on (n,γ_0) $(n,n'\gamma)$ and neutron total cross sections. The arrangement for the experiments involving γ-rays is shown in Fig. 5.

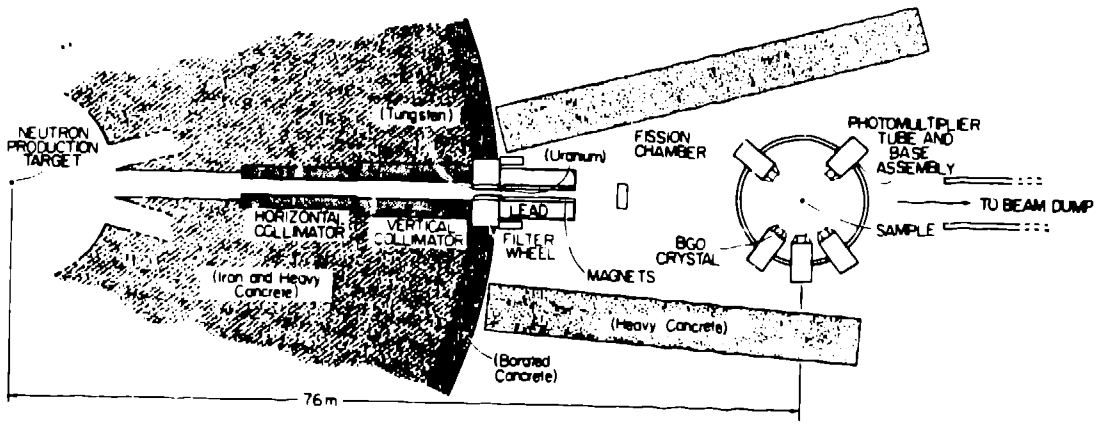

Fig. 5 - The experimental apparatus for (n,γ_0) and $(n,n'\gamma)$ spectral and angular distribution measurements as a function of neutron energy. The BGO crystals provide adequate resolution without the neutron sensitivity of NaI.

Five BGO detectors can be arranged at various angles around the sample which is located at 7.6 M from the source. The ^{235}U fission chamber is used as a flux monitor. Two examples of measurements with this system are shown in Figs. 6 and 7. Fig. 6 shows the A_0 coefficient in the angular distribution for production of the 2.12 MeV γ-ray between the first excited and ground states of ^{11}B. The upper portion of the figure shows the data between 2 and 20 MeV and the lower portion the data between 2 and 200 MeV. Ten or more peaks can be associated with known levels in the ^{12}B nucleus. Fig. 7 shows measurements of the reaction ^{40}Ca(n,γ_0). The abscissa is the neutron energy. The peak at 10.5 MeV incident neuclear energy is the giant dipole resonance located at 19 MeV excitation energy in ^{41}C The latter measurement was marginal at Target Area 1. At Target Area 2 the greatly enhanced neutron intensity, duty cycle, and resolution will allow much higher quality data. New facilities at Target Area 2 for the γ-ray measurements should be operational in the summer of 1985.

A number of other types of neutron-induced reactions are under consideration. Aspects of the fission process include total fission cross sections, energy dependent angular distibutions, energy dependent mass distribution, and (n,2n) or (n,3n) reactions on fissile targets. The full spectrum of neutron-induced reactions with charged particle in the final state such as (n,p) and (n,α) studies are under consideration. It appears that a useful technique might be developed for (n,n') studies.(3)

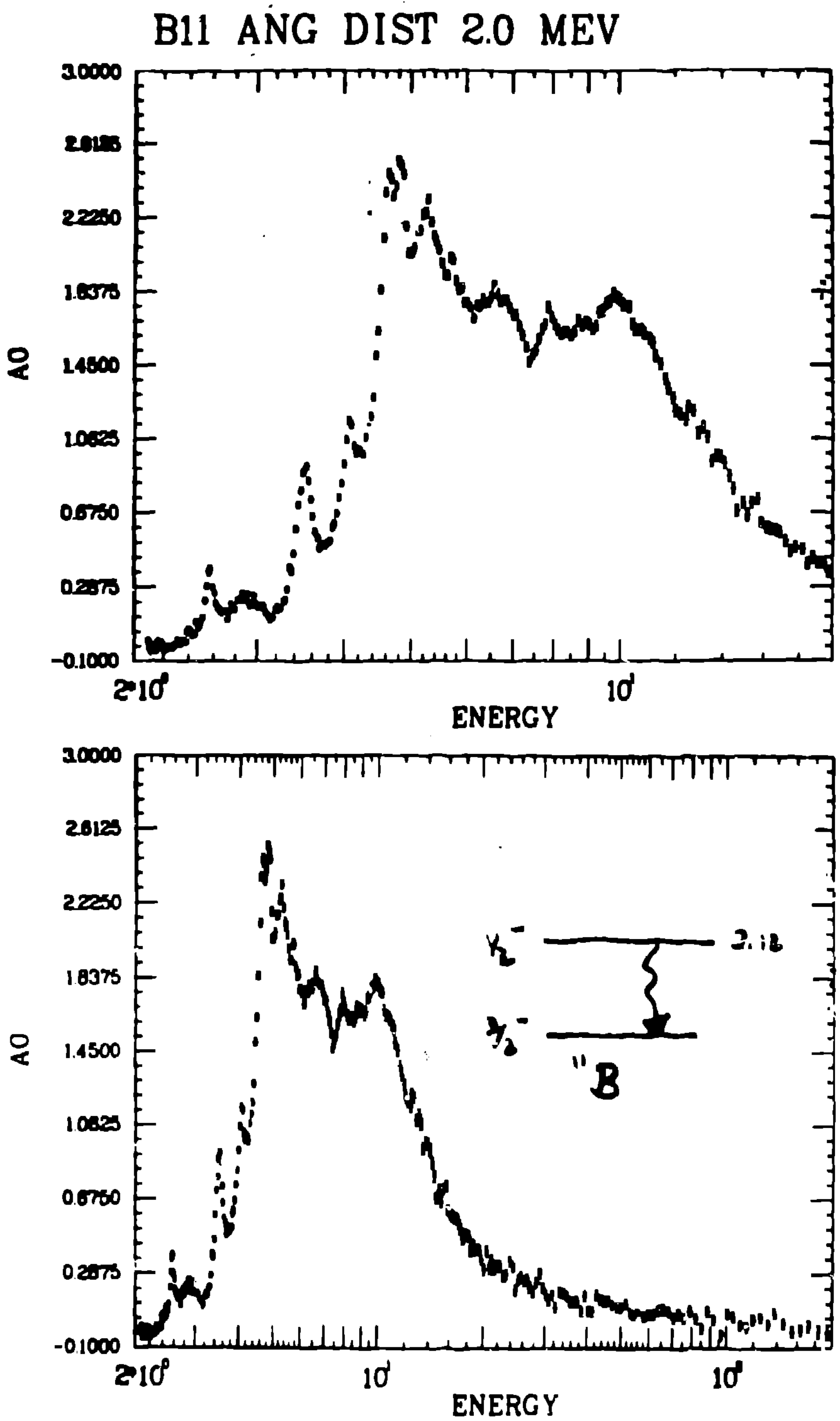

Fig. 6 - The a_0 coefficient of the angular distribution for production of the 2.12 MeV γray in ^{11}B via the (n,n') reaction over the neutron energy range from 2 to 100 MeV.

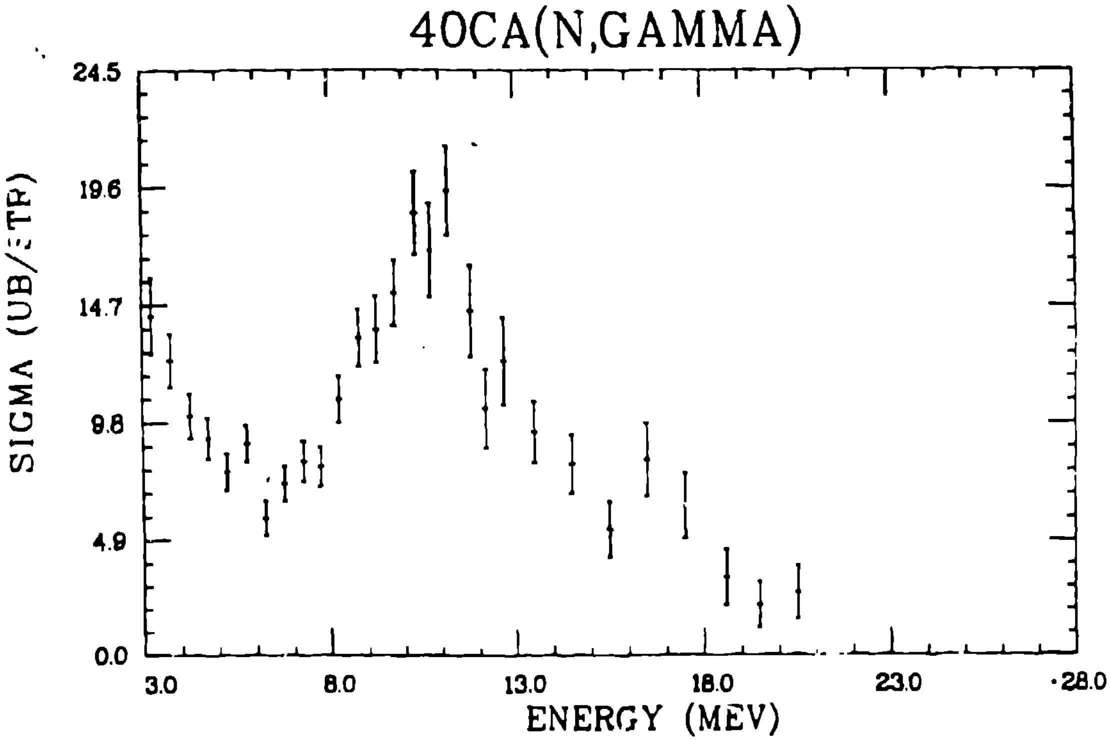

Fig. 7 - The production of the ground state gamma ray following neutron capture on ^{40}Ca. The peak is interpreted as the giant electric dipole resonance in ^{41}Ca.

Many of these experiments are traditionally done using monoenergetic variable energy neutron source techniques. A white neutron source has several advantages over monoenergtic sources especially where the energy dependence of a phenomenon is measured. Since a white source allows the measurement of all energies simultaneously, systematic errors associated with sequential measurements are reduced. The white source technique also reduces problems with time variations in neutron intensity, detector efficiency, bias levels, etc. A further advantage of the white source is that a number of different experiments can run simultaneously.

To illustrate the performance of a white source, a analysis was made for the (n,p) reaction including a comparison with the monoenergetic source technique. We assume the monoenergetic source reaction to be ^7Li (p,n)^7 Be at 0° and use the cross sections of Fig. 8 measured for proton energies up to 100 MeV. Neutron spectral measurements for this reaction indicate a fairly clean monoenergetic source with a resolution probably determined by the 0.431 MeV

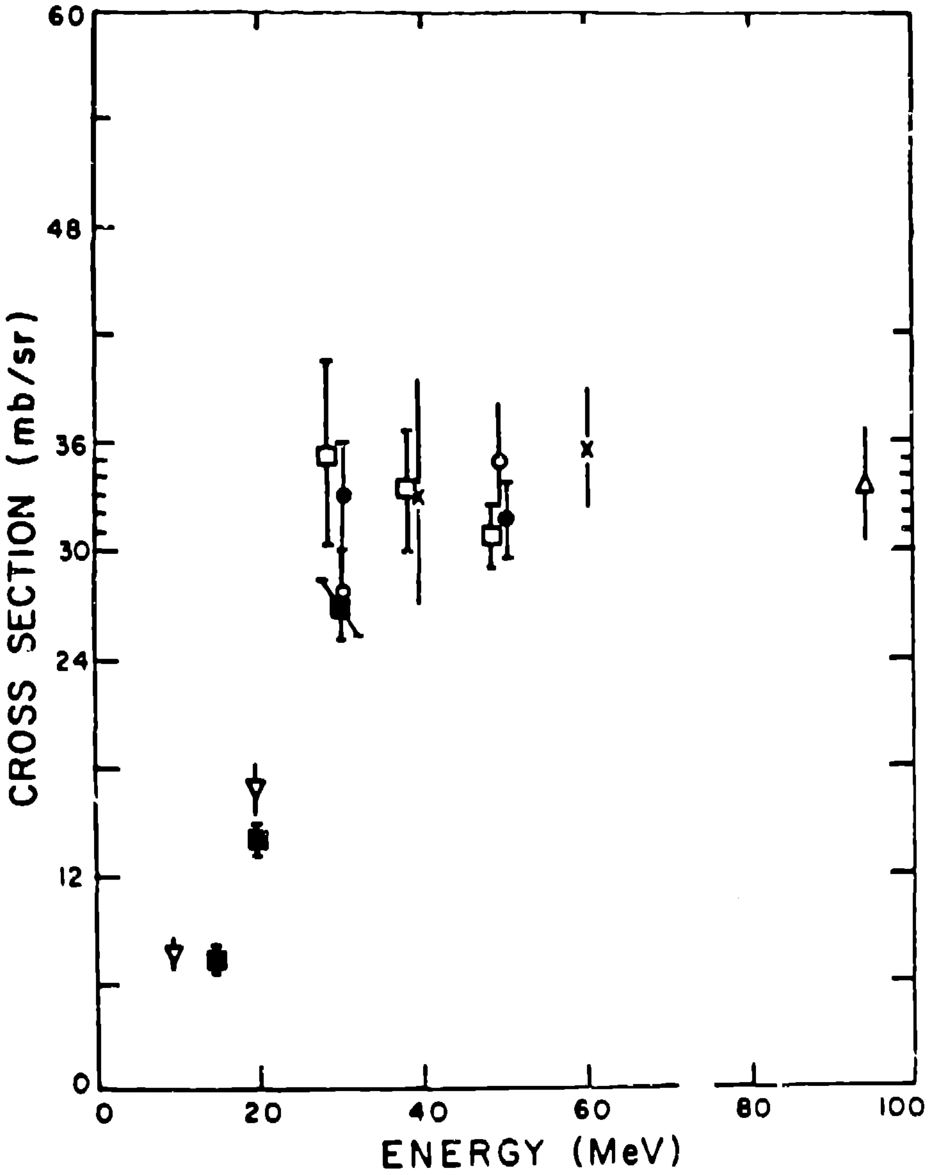

Fig. 8 - The cross section of the $^{7}Li(p,n)$ reaction at 0°
as a function of neutron energy.

separation between the ground and first excited states of ^{7}Be. Above 100 MeV a flat cross section of 33 mb/sr-MeV is assumed. In calculating the neutron yield the lithium target thickness is varied to allow a 1% energy resolution at every energy. (This resolution is limited at lower energies by the 0.431 MeV separation referred to above). Thus for 200 MeV neutrons the target is about 2 MeV thick. A magnet would be required to sweep the transmitted proton beam away from the forward direction, and shielding would be included to reduce backgrounds from off-angle neutrons striking the magnetic spectrometer. It is assumed that the object foil for the spectrometer is located 3 meters from the lithium target to allow space for the magnet and shielding. The neutron intensity on the object foil is given as n/cm^{2}-μs vs neutron energy in MeV by the indicated curve in Fig. 9.

To calculate the white source effective strength, we use intensities calculated by Russell[1] for thick target emission at 90° which are shown in Fig. 3 and thick target angular distributions measured by Howe.[5] The Target Area 2 layout requires that this experiment be set up at 22 meters which determines the neutron resolution at a value better than 1%.

The band width of the magnetic spectrometer is an important element in the comparison of the two techniques and its influence on the comparison depends to some degree on the nature of the experiment. We assume here that the purpose of the experiment is to measure the excitation function for the (n,p) reaction leading to a particular final state in the product nucleus. The data collection rate for the white source then depends directly on the band width of the magnetic spectrometer, which we take to be 20%. Under these conditions the neutron intensity per cm^{2}-μs is given as the indicated curve in Fig. 9. The two curves cross at about 300 MeV showing that this is an approximate transition point for the comparative value of the two techniques assuming the same proton current.

Since the maximum current for both the WNR/PSR and the Indiana University Cyclotron Facility (ICUF) is about the same, Fig. 9 should be directly useful for comparison of these facilities for the particular (n,p) experiment described here. Since the ICUF is over subscribed by about 300%, perhaps some of the load could be absorbed at the WNR/PSR. Above 300 MeV, the monoenergetic source appears to be superior if a facility is available which supplies the necessary current and energy. Presently there is no such facility in the U.S. so the usefulness of the WNR/PSR might be extended to energies significantly higher than 300 MeV. A proposed variable energy P^{-} or H^{-} source of neutrons being planned for Area B at LAMPF could fill in the higher energy gap and would be highly complementary to the WNR/PSR facility.

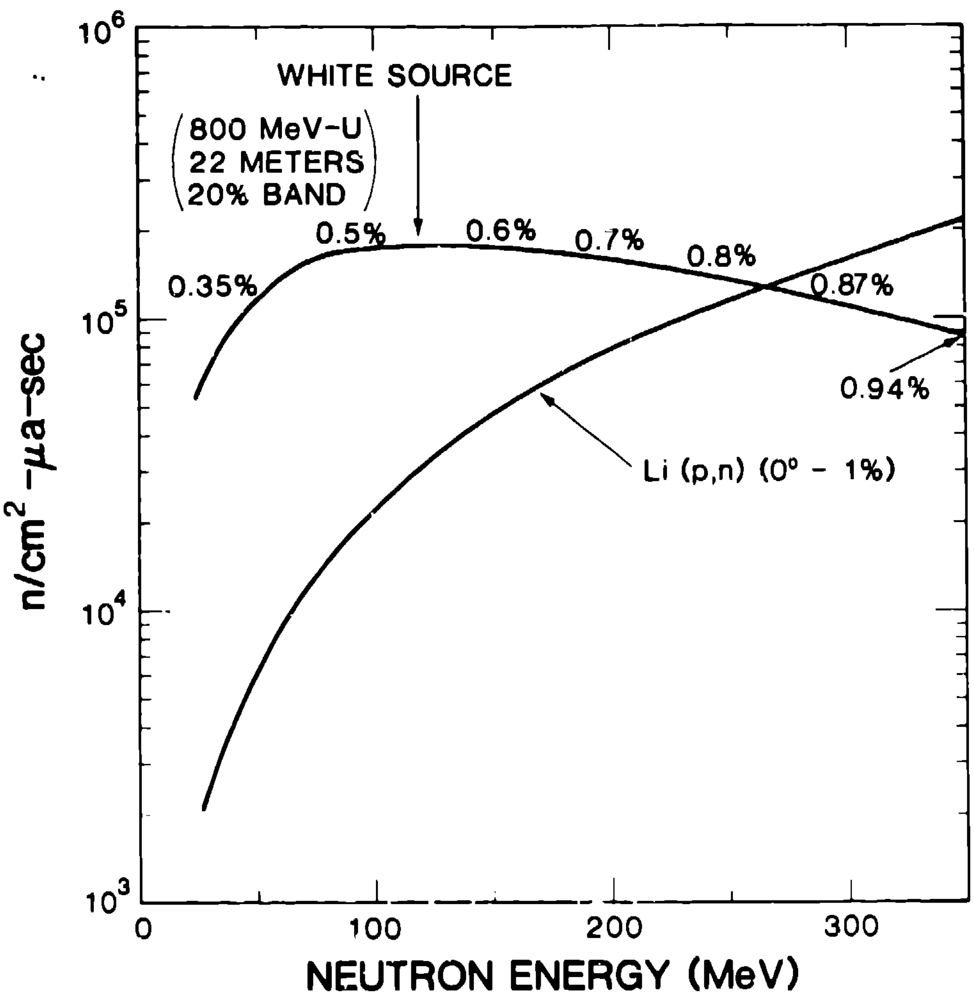

Fig. 9 - A comparison of white vs. monoenergetic neutron source effectiveness for the measurement of (n,p) reactions. The Li(p,n) monoenergetic source intensity is calculated for conditions which allow a 1% resolution in the neutron energy and therefore approximately the same resolution in the proton spectrum. It is assumed that the proton spectrometer allows a coverage of 100% of the proton energy spectrum. The curve for the white source is calculated assuming 800 MeV protons striking a thick ^{238}U target with emission angle of 15°. The proton spectometer placed at 22 meters allows a 20% band width to be measured at one setting. The numbers above the curve indicate the % neutron resolution at various energies.

SUMMARY

Target Area 2 is being developed as a multiuse white neutron source for a variety of measurements in the 10-800 MeV range. Average current is expected to be about 6 μa at a rate of approximately 50,000 Hz and with a pulse width of about 0.4 nsec. The facility will be operational about 80% of the time that LAMPF operates and will have several flight paths as sites for independent experiments. The facility will begin operation in the summer of 1985. While Los Alamos staff will use the facility for a variety of basic and applied research, it is expected that substantial use of the facility can be made by outside investigators. An outside group might also be able to construct and operate its own spectrometer at the WNR/PSR. Outside use is encouraged and interested persons are urged to contact one of the authors.

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